Appendix A — Superconductivity: A Brief Explanation

A basic characteristic of every substance is the degree to which it allows a flow of electrons to pass through it; those that resist are classified as insulators while those offering little resistance are considered conductors. To understand the phenomemon of superconductivity — the flow of electricity through a material with no resistance — an understanding of interactions at the atomic level is necessary. Atoms are composed of a large nucleus surrounded by clouds of electrons distributed in one or more layers; different substances have different numbers of electrons in the outermost layer. An electric current is simply the movement of free electrons from atom to atom as they jump from outer electron layer to outer electron layer. If the outermost layer is full of the atom's own electrons, there is no room for a free electron to jump to; that makes the substance an insulator. If there is room for more electrons in the outermost layer, then the substance is a conductor.

Another key determinant of conductivity is the arrangement of atoms within a substance. Interactions between the outermost electron layers of each atom determine the distance between atoms and the three-dimensional arrangement of atoms within the substance, both of which influence the level of conductivity. The farther apart atoms are, the more energy it takes for an electron to jump from one to another. On the other hand, if atoms are too closely packed, the number of jumps an electron must make to travel from one end of the conductor to the other increases dramatically. Certain atomic arrangements also provide relatively straight paths for electrons to follow, while others present complicated obstacle courses.

Third, heat causes atoms to vibrate. The degree of vibration is proportional to the temperature. At -459.67 degrees farenheit or absolute zero (0 degrees Kelvin), there is no thermal energy and molecular vibration stops. (Each atom's nucleus and electron cloud are still in motion, however, causing residual atomic vibration.) When cooled to near this temperature, many substances lose all resistance to an electric current, theoretically due to the absence of vibration. At such low temperatures, substances that are insulators at room temperature can become conductors and vice versa. The exact temperature needed to allow superconductivity is called the critical temperature and it varies depending on the substance involved. Current theory is barely adequate to deal with atomic interactions at these frigid temperatures.

While it is easy to forecast whether a particular pure element will be a conductor or insulator, the task is much more complex when mixtures of elements are involved. In fact, it is the interaction of elements that leads to the wide range of conductivity seen in the everyday world. We are just beginning to really understand and manipulate the electric properties of materials at the molecular level. Plastics, for example, are normally considered good insulators. Special combinations and processes, however, can produce plastics that are fairly good conductors. Our rudimentary understanding of this phenomenon is highlighted by a recently discovered new class of high-temperature superconducting materials.

Prior to the high-temperature breakthrough, scientists believed that a special combination of atomic vibration and three-dimensional atomic structure resulted in superconductivity. When cooled to close to absolute zero, the atomic vibration of various metals and alloys was reduced to the point where it became only a modest drag on the flow of electrons. In addition, the bonds between the metal atoms were just right to force a pair of free electrons into close association (not a normal condition since electrons have the same electric polarity and will thus repel each other). A superconducting current occurs as coupled electron pairs move through the atomic lattice unhindered by atomic vibration.

The new high-temperature superconductors have forced a reevaluation of theory, which predicted that superconductivity was impossible above about 40 degrees Kelvin or -388 degrees farenheit. Current speculation proposes that defects in the atomic structure of ceramics and the atomic vibration of atoms combine to reinforce the vibration of free electrons, allowing them to move through the ceramic in waves without resistance. This hypothesis is very tentative, however.

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Appendix B — A Summary of the Mid-Term Report of the Industrial Superconductor Technology Development Roundtable, August 24, 1987

(unoffical translation)

Issues and Goals

I. Investigation of high-temperature and room-temperature superconductors - The discovery of ceramic oxide superconductors and the rise in critical temperatures to the level of liquid nitrogen has had a major impact on materials research. Research must be directed toward the development of room-temperature superconductors based on study of the high-temperature group. A variety of these materials with a variety of parameters must be developed so that they may be widely applied.

A. Oxidized materials - Experiments from all angles should be conducted to fully understand these materials and find ways to stabilize them. Although it is difficult to do so now, the search for other superconductors that can be cooled with liquid nitrogen should be expanded. It is therefore necessary to develop a complete theoretical understanding of these materials, including an understanding at the atomic level. This understanding will hopefully lead to the development of other classes of superconductors.

B. Organic materials - While research into raising the critical temperature of organic superconductors has just begun, it appears they are much lower than the ceramic oxides. Nevertheless, because organic superconductors offer merits in terms of stability and processing temperatures, future research is necessary. It may be that an understanding of the principles of ceramic oxides will lead to breakthroughs in the organic field.

C. Metallicized composites and alloys - At least a part of current research should be directed toward these materials. Although these materials have lower critical temperatures than ceramic oxides and will probably be commericalized after the ceramics, they offer superior physical properties that will be important.

II. Industrial and process technology - Application of superconductors in the electronics and electric power areas requires development of materials with high current densities and high magnetic fields.

A. Thin film technology - Thin films are indispensable for electronics applications. The development of multilayer superconductor technology and very thin metallicized film technology, however, may open new semiconductor manufacturing possibilities. Nevertheless, thin film superconductor technology must be pursued.

1. Understanding the basic characteristics of high-temperature ceramic oxide superconductors - This includes: thin film characteristics, the relationship between crystal and superconductive qualities, and noncrystalline and multicrystalline films.

2. Very precise control of thin film formation - Ways to control layering, purity and crystallization must be developed.

3. Production of thin films with high critical temperatures and current densities - Materials with current densities of at least 100,000 amperes per square centimeter must be developed to achieve commercialization.

4. Production of monocrystalline films - To achieve monocrystalline films, the unusual characteristics of these ceramics must be exploited. Epitaxial technology must be developed.

5. Low-temperature thin film production - Temperatures presently needed to produce the ceramics (900 degrees centigrade) are so high as to make their use with other materials difficult. The necessary temperature must be reduced to at least 450 degrees centigrade.

6. Multilayer production and design - Methods to insure the purity and stability of each layer, and new methods of exploiting this must be developed.

B. Wire formation technology - While the problem of forming the ceramics into wires is paramount, increasing the current density and magnetic field density resistance is also important. The imperfections, coherence length (the average distance between electrons in a superconductor) and free electron concentration must be understood.

1. Understanding how the imperfections in the ceramics contribute to magnetic flux density must be considered from all angles.

2. If the current density can be raised (and the materials are used in ICs), methods to prevent magnetic flux lines from changing in the chip must be found. Impurities and particles in the chip used to stop magnetic flux changes at a pin are called pinning centers. Current pinning center technology is inappropriate for the different qualities of the ceramic superconductors. New technology, perhaps based on thin films and nonmagnetic materials, must be developed.

3. It is possible that the new ceramic superconductors will solve the problem of low levels of free electrons. When both a high current density and high magnetic field resistance are needed, however, current technology is inadequate. If wires for such applications are to be developed, the following problems must be addressed:

a. High capacity superconducting materials technology (stability and predictability)
b. Understanding the relationships between electromagnetism, high current density and high voltage
c. High magnetic field-producing, continuous wire technology
d. Superconducting magnet technology
e. Superconductivity measurement technology

Existing production technologies, such as chemical vapor deposition and sputtering techniques for thin films as well as thin layer ceramic techniques are being tested on these problems. Perhaps use of the new superconductors with existing conductors should be tried. Finally, a technology database for this field should be created.

III. Electronics applications

A. Device processing and manufacturing technology - Current IC production methods (lithography and etching) are inadequate. New methods suited to the electronic and physical characteristics of the ceramics must be developed. The hardness, coherence and tunneling electron qualities of the new materials pose special problems.

B. Electric wire and component technology - Many problems must be addressed before a cheap superconductor can revolutionize common electric products. A database containing all information on the new materials would help.

C. Research and development of entirely new devices - The unusual qualities of the new superconductors (high temperature, large electron gap, storage capacity and magnetic qualities) should be exploited in new ways.

1. Superconducting transistors (bipolar and FET types)

2. Superconducting measurement devices - The new ceramic superconductors can be used to make more accurate, more sensitive and smaller measurement devices, such as the superconducting quantum interference detector (SQUID). Devices to measure activity within the brain, track information networks and detect changes at the micron level are possible. Superfast detectors (sub-picosecond) should be an immediate priority.

3. New devices - Whole families of new devices for optoelectronics and electromagnetic applications can be developed if breakthroughs on understanding the new ceramics can be made.

IV. Energy systems - Low-loss transmission lines, supermagnetic generators, high efficiency motors, small motors, high speed motors and very large motors can be developed with practical superconductors.

1. a. Power generating equipment - Armature cores and windings will be developed in cooperation with western allies.
   b. i. Construction of a 100-kw test plant to measure building costs.
      ii. Measurement of efficiency gains
      iii. Application to other motors and generators
   c. i. Develop complementary alloys and materials
      ii. New armature manufacturing techniques
      iii. Develop high reliability systems

2. Superconducting electric storage devices

   a. The problems of ceramic oxide stability and containment of strong magnetic fields must be solved. Thyristor technology will also have to be adapted.
   b. The United States and Japan are working on 1-5 gigawatt systems, but even bigger systems (800 megajoules and 10,000 times current capacities) must be developed.
   c. The dynamics of cooling large coils and cores must be investigated for their mechanical, electric and magnetic effects.

3. Superconducting cable

   a. In addition to the problem of manufacturing a cable from the ceramic oxides, new housings and supports must be developed.
   b. Since many countries are working on this application, an all-out effort is needed.
   c. Methods for producing continuous high voltage lines, stable and inexpensive cables are needed.
   d. Simplified fuses and high efficiency cooling systems are also needed.

4. Superconducting transformers - These must be developed to complement superconducting generating and transmission systems.

5. Superconducting magnets for nuclear fusion reactors

   a. The high efficiency, current density and large magnetic field make superconductors ideal for nuclear fusion reactors. However, the necessary cooling equipment must be developed.
   b. While fusion reactors are being developed, superconductors should be employed in other areas, such as magneto-hydrodynamic (MHD) generators, and other high energy systems.
   c. Adaptation of technology developed in other areas, such as nuclear magnetic resonance (NMR) and computer-aided tomography (CAT) scanners, should be investigated.
   d. New approaches made possible by the ceramic superconductors should be explored.

V. Information, medical, transportation and other uses

1. High speed computers - The new ceramics will make supercomputers with system clock speeds of one nanosecond possible, while at the same time reducing their size and energy consumption. Design, manufacturing and cooling problems must be overcome.

2. Medical systems - Smaller (perhaps portable), more sensitive, more efficient, and less expensive NMR machines should be developed. Magnetic and chemical detectors should also be explored.

3. Magnetic-levitation train (linear motor car) - Mastery of all aspects of large-scale application of the new ceramics will be required to build a mag-lev train. Control, cooling, shielding and other large-scale phenomena must be understood.

4. Electromagnetic naval propulsion - Large gains in energy efficiency are possible if hurdles can be overcome. Magnetic fields of 10-20 tesla will be required to drive a vessel through the water by electromagnetic repulsion and attraction. Steering, control and shielding questions must be answered.

5. Outerspace systems - The environment of outerspace may be particularly suited to the production of ceramic superconductors. A microgravity environment solves some problems the ceramic oxides develop in the microelectronics field. Second, the ceramics themselves can be used to build more efficient space platforms and satellites, as well as for a whole range of highly sensitive space-based sensors. Scientific space exploration will surely benefit.

Policy Recommendations

I. Promotion of research and development

A. Exploration of both the fundamental and applied aspects of the new materials must be pursued. The wide range of potential applications and the numerous problems means that the high costs of superconductor R&D must be supported by the government.

1. Basic R&D should be the focus of the national universities and government research centers.

2. Applied research should include development of new ceramics, clarifying physical traits, basic processing technology and other technologies.

3. Because development of complete systems using superconductors will be expensive, cooperation with the private sector is vital.

Research topics: understanding the fundamental characteristics of ceramic superconductors; development of room temperature superconductors; development of industrial and process technology; basic superconductor research at the atomic level; development of electric power applications; applications of superconductors to basic research.

B. A structure to support superconductor research should be established.

1. Activities of the national research laboratories - Exploration of basic questions and long-term applications should be pursued. Foreign researchers should be invited to participate. A special research center should be built in Tsukuba, Chiba prefecture. National laboratories should take a leading role in this research.

2. Expanding basic research at universities - The key role of the universities in the superconductor field is revealed by the 72 papers Japanese researchers presented at the recent 18th international conference on low temperature materials. Not only must funding for university research be increased, but experiments in the areas of production, control and basic theory should be conducted.

3. National research projects - To realize the full potential of the new materials, government, academic and private research efforts must be coordinated. Because the cost of research and development is high, efforts should be concentrated in a few centers.

4. Cooperative research - In accord with the above, cooperative research should be strengthened.

5. Establishment of a support structure for private research - Although many of the private research efforts, which were initiated immediately after the ceramic breakthrough, are on the verge of some practical applications, the newness of the field presents problems. The inherently high risk calls for a coordinated, structural approach to research, including allocation of funds, researchers and expertise from all companies such as wire makers, electronics producers and ceramics firms. The effort must also include foreign researchers. This structure will be critical to the successful development of complete systems based on superconductors.

6. Patents - Because superconductor research will generate a large number of patents, it is imperative to quickly study ways to improve the current system as well as to bring it into line with international standards.

II. International cooperation and technology flows - Since the breakthrough has the potential to revolutionize every aspect of living, international competition is naturally fierce within Japan and the United States and between the two nations. Over the past year there have been instances of conferences, research exchanges and healthy scientific debate between the two countries. This "competition and cooperation" should be promoted. Japan can and should make a significant contribution to the global effort to understand and employ these new materials, sharing its knowledge with others.

A. Joint research at national laboratories - The accumulation of first-class knowledge on superconductors at national laboratories is growing and as national research centers in other countries do, Japan's laboratories must support international cooperation. While the government is willing to support joint research and researcher exchanges, more concrete steps must be taken in the national budget. Exchange of researchers is particularly important for Japan to support. Efforts must be made to liberalize the research environment at the national laboratories as well as liberalize funding and management. The image sent to foreigners is that Japanese laboratories are closed; the level of expertise is high but the knowledge must be internationalized. Efforts to invite foreign researchers must be increased.

B. Internationalization of national projects - Although international cooperation is already part of the government's research program it must be increased in the area of superconductors. International technology flows must be promoted. Greater foreign participation in all areas of national projects should be pursued.

C. Disseminating national technology information through workshops and symposia - International superconductor efforts can benefit greatly from the dissemination of Japan's accumulation of technology. By holding seminars and workshops at home and abroad, Japan can accomplish this as well as improve its image.

Suggestions include: Quickly reporting research results abroad; technology transfers via international symposia and workshops; expanded exchange of researchers; and providing foreign access to Japanese databases. Since private re-

search is advancing quickly, corporate participation in these technology transfers is vital. A study of how to encourage private participation should be started.

D. International organizations - Existing international organizations should be enlisted in this global effort.

III. Research surveys and other measures - To better plan improvements, a survey of current efforts and other measures should be conducted.

A. Survey on research efforts - A survey of basic research efforts on superconductors, new materials and other related fields is needed. Efforts to apply new materials to current devices should cover all fields. The implications for society and the economy should also be studied.

B. Survey on new applications and fields - Potential areas of application and their impact on other areas of science and technology must be explored. Creative thinking and opinions from all fields should be gathered to smooth the way for future developments.

C. Development of measures and standards - Japan should cooperate in international efforts to establish common standards and measurements in this new field.

D. Establishment of a database - A national database holding all relevant information would be a major asset to the research program. International access to it must also be provided.

E. Survey of corporate efforts and support structures - A survey on industry's plans and thoughts would aid development of a national research support structure.

Source: Ministry of International Trade and Industry.

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Appendix C -- President Reagan's July 21, 1987 Superconductivity Initiative

1. Amending the National Cooperative Research Act to expand the concept of a permissible joint venture to include some types of joint production ventures. This is a particularly important step that would ease the risk of antitrust litigation perceived by U.S. businesses that could otherwise benefit from pro-competitive joint ventures. If enacted, it could benefit not just developments using superconductivity, but other high technology products as well.

2. Amending U.S. patent laws to increase protection for manufacturing process patents. This would enable U.S. owners of process patents to obtain damages for infringement where products made with those processes are imported into the United States.

3. Authorizing federal agencies to withold from release under the Freedom of Information Act commercially valuable scientific and technical information generated in government-owned and -operated laboratories that, if released, will harm U.S. economic competitiveness.

4. Establishing a "Wise Men's" Advisory Group on Superconductivity under the auspices of the White House Science Council. This would be a small group of three to five people from industry and academia that would advise the administration on research and commercialization policies.

5. Establishing a number of "Superconductivity Research Centers" and other similar groups that would conduct important basic research in superconductivity and serve as repositories of information to be disseminated throughout the scientific community.

a. The Department of Energy will establish three SRCs, as well as a computer data base:

- o Center for Superconductivity Applications at the Argonne National Laboratory
- o Center for Thin Film Applications at the Lawrence Berkeley Laboratory
- o Center for Basic Scientific Information at the Ames Laboratory
- o Computer Data Base on Superconductivity at the DOE Office of Scientific & Technology Information.

b. The Department of Commerce will establish a Superconductivity Center at the National Bureau of Standards laboratory near Boulder, Colorado. The center will focus on electronic applications of high-temperature superconductivity.

c. The National Aeronautics and Space Administration is establishing a coordinating group on superconductivity activities at its office of Aeronautics and Space Technology.

d. The National Science Foundation will augment its support for research in high-temperature superconductivity programs at three of its materials research laboratories. In addition, NSF is initiating a series of "quick start" grants for research into processing superconducting materials into useful forms including wires, rods, tubes, films and ribbons.

e. The Department of Defense is developing a multi-year plan to ensure use of superconductivity technologies in military systems as soon as possible. DOD will spend nearly $150 million over three years.

DOD will build on its long experience in superconductivity R&D to systematically define the engineering parameters for high-temperature superconducting materials; develop the required processing and manufacturing capabilities; and accomplish the necessary development, engineering and operational prototype testing of superconductors.

Small-scale applications with commercial spin-off potential include sensors and electronics. Potential large-scale applications include compact, high-efficiency electric ship drives; electrical energy storage; pulsed power systems; and free-electron lasers.

6. Urging all federal agencies to implement quickly the steps outlined in Executive Order 12591 designed to transfer technology developed in federal laboratories into the private sector and encourage federal, university and industry cooperation in research. The White House Science Advisor will report to the president by December 1, 1987 on progress in implementing the executive order, particularly with regard to superconductivity.

7. Directing the Patent and Trademark Office to accelerate the processing of patent applications and adjudication of disputes involving superconductivity technologies when requested to do so by the applicant.

8. Directing the NBS to accelerate its efforts to develop and coordinate common standards (e.g. measurement methods, standard reference materials and supporting technical data) in the United States and internationally for superconductors and related devices.

9. Encouraging federal agencies to continue to reallocate FY 1987 funds into superconductivity basic research, applied research in enabling technologies and prototype development. Agencies are directed to place a high priority on this area in FY 1988 funding and FY 1989 planning.

10. Requesting that DOD accelerate prototype work in sensor, electronic and superconducting magnet-based military applications and that the Department of Commerce accelerate development of prototype devices in detection and measurement of weak magnetic fields.

11. Taking advantage of the opportunity presented by the current negotiations for renewing the U.S.-Japan Agreement on Science and Technology to seek reciprocal U.S. opportunities to participate in Japanese government-supported research and development, including superconductivity.

In April, the president issued Executive Order 12591, Facilitating Access to Science and Technology, directed at encouraging increased commercialization of the U.S. science and technology enterprise.

Source: Business America, August 17, 1987.

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Appendix D

Table 1: Japan's R&D Expenditures, FY 1981-FY 1985

(in billions of yen and percent)

a. By Organization

Fiscal Year	Companies	Research Institutions	Universities	Total
1981	Y3,629.8	Y906.9	Y1,445.6	Y5,982.4
Change	15.5%	18.7%	7.9%	14.0%
Share	60.7%	15.2%	24.2%	100.0%
1982	4,039.0	949.3	1,540.4	6,528.7
Change	11.3%	4.7%	6.6%	9.1%
Share	61.7%	14.5%	23.6%	100.0%
1983	4,560.1	971.0	1,649.6	7,180.8
Change	12.9%	2.3%	7.1%	10.0%
Share	63.5%	13.5%	23.0%	100.0%
1984	5,136.6	1,033.1	1,724.2	7,893.9
Change	12.6%	6.4%	4.5%	9.9%
Share	65.1%	13.1%	21.8%	100.0%
1985	5,939.9	1,160.6	1,789.8	8,890.3
Change	15.6%	12.3%	3.8%	12.6%
Share	66.8%	13.1%	20.1%	100.0%

b. By Source

Fiscal Year	Government	Private	Foreign	Total
1981	Y1,612.4	Y4,363.8	Y6.1	Y5,982.4
Change	10.1%	15.6%	24.5%	14.0%
Share	27.0%	72.9%	0.1%	100.0%
1982	1,666.2	4,855.5	7.0	6,528.7
Change	3.3%	11.3%	14.8%	9.1%
Share	25.5%	74.4%	0.1%	100.0%
1983	1,721.4	5,451.1	8.2	7,180.8
Change	3.3%	12.3%	17.1%	10.0%
Share	24.0%	75.9%	0.1%	100.0%
1984	1,777.8	6,108.6	7.6	7,893.9
Change	3.2%	12.1%	-7.3%	9.9%
Share	22.5%	77.4%	0.1%	100.0%
1985	1,867.3	7,014.9	8.1	8,890.3
Change	5.0%	14.8%	6.6%	12.6%
Share	21.0%	78.9%	0.1%	100.0%

Source: Management and Coordination Agency, Report on the Survey of Research and Development.

Table 2: Japan's R&D Expenditures by Industry, FY 1984-FY 1985

(in billions of yen and percentage change)

	FY 1984		FY 1985	
	Total	Change	Total	Change
Agriculture	Y4.8	-15.5%	Y4.5	-6.1%
Mining	18.8	20.2	21.7	15.8
Construction	116.1	14.6	110.8	-4.6
Manufacturing	4,776.5	12.2	5,543.6	16.1
Food Products	123.7	11.3	133.5	7.9
Textiles	59.5	16.6	62.6	5.3
Pulp and Paper	29.1	13.3	32.4	11.2
Publishing and Printing	13.9	20.6	18.4	33.1
Chemicals	852.8	10.1	936.4	9.8
Industrial Chemicals and Synthetic Fibers	346.3	16.3	377.8	9.1
Oils and Paints	84.3	12.4	89.2	5.9
Pharmaceuticals	295.3	1.9	341.9	15.8
Other	127.0	13.4	127.4	0.4
Petroleum and Coal Products	56.0	12.3	68.3	21.9
Plastic Products	64.0	23.5	65.6	2.4
Rubber Products	68.4	18.4	79.8	16.7
Nonmetallic Mineral Products	131.3	15.9	174.2	32.7
Steel	192.1	- 3.2	240.4	25.2
Nonferrous Metals	87.7	18.5	100.5	14.7
Fabricated Metal Products	83.5	0.8	102.7	23.0
Nonelectric Machinery	337.5	8.3	382.7	13.4
Electric Machinery	1,634.5	15.4	1,938.2	18.6
Communications and Electronics Equipment	1,096.4	14.4	1,322.0	20.6
Other	538.2	17.6	616.2	14.5
Transportation Equipment	808.2	13.1	935.7	15.8
Motor Vehicles	686.7	13.3	797.2	16.1
Other	121.5	11.8	138.5	13.9
Precision Machinery	167.4	5.4	201.7	20.5
Other	67.0	0.9	70.6	5.4
Transportation, Communications and Utilities	220.5	22.3	259.3	17.6
Total	5,136.6	12.6	5,939.9	15.6

Source: Management and Coordination Agency, Report on the Survey of Research and Development.

Table 3: Japan's Ratio of Corporate R&D Expenditures to Gross Sales, by Industry, FY 1984-FY 1985

(in percent)

Industry	FY 1984	FY 1985
Agriculture	0.24%	0.24%
Mining	0.63	1.03
Construction	0.47	0.49
Manufacturing	2.34	2.69
Food Products	0.60	0.77
Textiles	1.16	1.18
Pulp and Paper	0.66	0.71
Publishing and Printing	0.61	0.68
Chemicals	3.46	3.79
Industrial Chemicals and Synthetic Fibers	2.47	2.80
Oils and Paints	3.09	3.14
Pharmaceuticals	6.49	7.04
Other	3.76	3.61
Petroleum and Coal Products	0.27	0.38
Plastic Products	1.94	1.75
Rubber Products	2.62	2.86
Nonmetallic Mineral Products	1.96	2.61
Steel	1.52	1.94
Nonferrous Metals	1.64	1.92
Fabricated Metal Products	1.46	1.59
Nonelectric Machinery	2.59	2.74
Electric Machinery	4.55	5.10
Communications and Electronics Equipment	4.60	5.25
Other	4.45	4.82
Transportation Equipment	2.76	2.90
Motor Vehicles	2.90	2.96
Other	2.20	2.61
Precision Machinery	4.08	4.49
Other	0.92	0.97
Transportation, Communications and Utilities	0.84	0.98
All Industry Average	1.99	2.31

Source: Management and Coordination Agency, Report on the Survey of Research and Development.

Table 4: Expenditures on Selected Science Programs, by Agency, FY 1986-FY 1987

(in millions of yen)

	FY 1986	FY 1987
Defense Agency		
Technology development	Y65,259	Y73,286
Science and Technology Agency		
Agency research (including four air and space development organizations)	25,025	26,494
Physical Chemistry Research Institute	13,793	14,692
New Technology Development Association	1,737	2,064
Science and technology promotion survey	4,514	4,992
Space Development Association	90,659	92,648
Ocean development research	6,631	7,710
Ocean Science and Technology Center	6,437	7,516
Japan Nuclear Development Research Institute	101,556	99,462
Japan Reactor Development Center	65,925	64,289
National Nuclear Research Laboratory	1,774	1,789
Research management costs	8,497	8,942
Environment Agency		
National Disaster Research Institute	4,266	4,099
National Water-borne Disease Center	426	390
National Disaster Prevention Institute	2,625	2,474
Disaster prevention survey	883	839
Foreign Ministry		
International Atomic Energy Commission	2,578	2,531
OECD Nuclear Power Committee	181	197
Finance Ministry		
Brewing Research Institute	329	335
Education Ministry		
Ministry research (including six education centers)	6,680	6,973
Research grants	43,500	45,080
Japan Technology Promotion Council grants	3,781	4,211
Health Ministry		
Agency research (including seven population research projects)	9,858	9,867
Research grants	12,860	13,972
Radiation effects research	1,946	1,980
Health science research	2,842	3,518
Cancer research projects	1,388	1,638
International cancer research	132	105
Medical and drug information system	263	221
Agriculture Ministry		
Agency research laboratories (including 18 agricultural research centers)	44,547	44,863
Agricultural technology development	9,370	9,379
Large-scale projects	1,366	1,275
Biotechnology development	1,294	1,334
Research machinery and equipment	2,066	2,066
Agricultural technology promotion	2,090	2,090

Table 4 (continued)

(in millions of yen)

	FY 1986	FY 1987
Agriculture Ministry (continued)		
Agricultural machinery research	Y810	Y813
Red tide research	224	234
Food product technology	602	505
International Trade and Industry Ministry		
Agency research (including 15 research centers)	25,176	25,515
Large-scale industrial technology projects	5,275	4,504
Computer industry promotion projects	4,501	4,051
Next-generation basic technology projects	5,644	4,850
New energy technology projects	2,378	2,010
Energy conservation projects	1,026	760
Private transportation project (YXX aircraft)	714	714
Private aircraft jet engine project (V2500)	3,987	3,987
Small business technology improvement	1,397	2,002
Transportation Ministry		
Agency research (including four ship technology centers)	7,168	7,252
Geostationary weather satellite management	2,032	2,126
Geostationary weather satellite launches	2,167	3,246
Magnetic levitation train technology	300	295
Posts and Telecommunications Ministry		
Electrotechnical laboratories	4,126	4,037
Construction Ministry		
Agency research (including one engineering center)	4,435	4,497

Source: Management and Coordination Agency, Report on the Sruvey of Research and Development.

Table 5: Japanese Government R&D Expenditures, FY 1986

(in millions of yen and percentage change)

	Science Promotion	Energy Research	Other Research	Special Research	Total
Diet	Y517	Y0	Y0	Y0	Y517
	0.0%	--	--	--	0.0%
Japan Technology Council	0	0	863	0	863
	--	--	-2.8%	--	-2.8%
Police Agency	899	0	0	0	899
	6.1%	--	--	--	6.1%
Hokkaido Development Agency	142	0	0	0	142
	0.7%	--	--	--	0.7%
Defense Agency	0	0	66,133	0	66,133
	--	--	12.7%	--	12.7%
Economic Planning Agency	704	0	0	0	704
	0.1%	--	--	--	0.1%
Science and Technology Agency	154,277	167,708	8,497	89,860	420,342
	5.0%	1.2%	-49.7%	7.2%	1.7%
Environment Agency	8,320	0	0	0	8,320
	-2.4%	--	--	--	-2.4%
Land Agency	210	0	0	0	210
	-29.8%	--	--	--	-29.8%
Justice Ministry	808	0	0	0	808
	2.7%	--	--	--	2.7%
Foreign Ministry	0	2,578	4,017	0	6,594
	--	-2.1%	10.6%	--	5.2%
Finance Ministry	329	0	0	610	938
	3.2%	--	--	5.5%	4.7%
Education Ministry	57,745	0	124,807	563,039	745,591
	3.3%	--	0.9%	5.4%	4.5%
Health Ministry	28,015	0	1,251	6,856	36,121
	6.4%	--	-3.5%	11.8%	7.0%
Agriculture Ministry	60,733	0	1,944	3,800	66,477
	2.0%	--	12.6%	*	8.5%
International Trade and Industry Ministry	56,427	3,404	10,675	147,050	217,557
	-4.5%	-22.7%	-0.9%	18.2%	9.5%
Transportation Ministry	11,511	0	571	1,188	13,271
	1.0%	--	-0.6%	2.0%	1.0%
Posts and Telecommunications Ministry	4,126	0	41	20,500	24,667
	-2.0%	--	-16.1%	105.0%	73.0%
Labor Ministry	599	0	1	2,371	2,970
	2.4%	--	0.0%	5.8%	5.1%
Construction Ministry	5,065	0	751	0	5,817
	3.1%	--	177.5%	--	12.2%
Home Affairs Ministry	527	0	0	0	527
	2.5%	--	--	--	2.5%
Total	390,954	173,690	219,551	814,773	1,598,969
	2.5%	0.6%	0.5%	8.3%	4.8%

*New allocation

Source: Management and Coordination Agency, Report on the Survey of Research and Development.

Table 6: Japanese Government R&D Expenditures, Planned FY 1987

(in millions of yen and percentage change)

	Science Promotion	Energy Research	Other Research	Special Research	Total
Diet	Y525	YO	YO	YO	Y525
	1.5%	--	--	--	1.5%
Japan Technology Council	0	0	856	0	856
	--	--	-0.8%	--	-0.8%
Police Agency	925	0	0	0	925
	2.9%	--	--	--	2.9%
Hokkaido Development Agency	143	0	0	0	143
	0.6%	--	--	--	0.6%
Defense Agency	0	0	74,135	0	74,135
	--	--	12.1%	--	12.1%
Economic Planning Agency	710	0	0	0	710
	0.8%	--	--	--	0.8%
Science and Technology Agency	160,765	163,966	8,942	91,559	425,232
	4.2%	-2.2%	5.2%	1.9%	1.2%
Environment Agency	7,914	0	0	0	7,914
	-4.9%	--	--	--	-4.9%
Land Agency	160	0	0	0	160
	-23.7	--	--	--	-23.7%
Justice Ministry	806	0	0	0	806
	-0.3%	--	--	--	-0.3%
Foreign Ministry	0	2,531	3,767	0	6,298
	--	-1.8%	-6.2%	--	-4.5%
Finance Ministry	335	0	0	674	1,009
	1.9%	--	--	10.5%	7.5%
Education Ministry	59,759	0	126,172	594,243	780,174
	3.5%	--	1.1%	5.5%	4.6%
Health Ministry	29,886	0	1,225	8,649	39,761
	6.7%	--	-2.0%	26.2%	10.1%
Agriculture Ministry	61,098	0	1,851	3,800	66,748
	0.6%	--	-4.8%	0.0	1.8%
International Trade and Industry Ministry	54,527	2,770	11,574	152,538	221,409
	-3.4%	-18.6%	8.4%	3.7%	1.8%
Transportation Ministry	12,758	0	754	1,004	14,516
	10.8%	--	32.0%	-15.5%	9.4%
Posts and Telecommunications Ministry	4,037	0	5	25,000	29,042
	-2.1%	--	-88.0%	22.0	17.7%
Labor Ministry	601	0	0.7	3,033	3,635
	0.4	--	0.0%	27.9%	22.4%
Construction Ministry	5,149	0	356	0	5,506
	1.7%	--	-52.6%	--	-5.3%
Home Affairs Ministry	536	0	0	0	536
	1.6%	--	--	--	1.6%
Total	400,634	169,267	229,639	855,500	1,655,040
	2.5%	-2.5%	4.6%	5.0%	3.5%

Source: Management and Coordination Agency, Report on the Survey of Research and Development.

Table 7: Japan's Technology Imports, FY 1950-FY 1985

(number of approved cases and value in billions of yen)

	Cases		Value	
	Total	Of Which New:	Total	Of Which New:
FY 1950-55	1,148	n.a.	Y24.9	n.a.
FY 1960	588	n.a.	34.2	n.a.
FY 1965	958	n.a.	60.1	n.a.
FY 1970	1,768	n.a.	155.9	n.a.
FY 1975	6,766	796	169.1	Y13.3
FY 1976	6,050	632	177.3	17.9
FY 1977	6,659	685	190.1	16.9
FY 1978	6,573	936	192.1	38.2
FY 1979	7,012	1,020	241.0	26.8
FY 1980	7,248	919	239.5	27.7
FY 1981	7,207	844	259.6	24.9
FY 1982	6,936	929	282.6	44.4
FY 1983	7,839	1,073	279.3	42.4
FY 1984	7,316	982	281.4	31.8
FY 1985	7,679	1,245	293.2	33.3

Table 8: Japan's Technology Exports, FY 1950-FY 1985

(number of approved cases and value in billions of yen)

	Cases		Value	
	Total	Of Which New:	Total	Of Which New:
FY 1950-55	n.a.	n.a.	Y0.3	n.a.
FY 1960	n.a.	n.a.	0.8	n.a.
FY 1965	n.a.	n.a.	6.1	n.a.
FY 1970	861	n.a.	21.2	n.a.
FY 1975	2,811	1,073	66.6	Y18.9
FY 1976	2,767	775	83.4	27.0
FY 1977	2,880	897	93.3	36.3
FY 1978	3,157	1,063	122.0	47.1
FY 1979	3,667	1,087	133.1	52.1
FY 1980	4,103	1,237	159.6	74.3
FY 1981	4,877	2,017	175.1	70.8
FY 1982	4,738	1,970	184.9	63.3
FY 1983	6,403	2,494	240.9	74.9
FY 1984	5,426	1,824	277.5	90.9
FY 1985	5,885	2,099	234.2	73.3

Source: Management and Coordination Agency, Report on the Survey of Research and Development.

Table 9: U.S. Patents Applied For and Granted, 1978-86

(cases)

	Applications		Granted	
	Total	By Japan	Total	To Japan
1978	109,300	10,400	70,500	7,100
1979	106,900	11,100	52,400	5,800
1980	113,000	13,100	66,200	6,600
1981	114,500	14,400	71,000	8,500
1982	118,400	17,300	63,300	8,800
1983	112,400	15,700	62,000	8,600
1984	117,985	18,289	72,149	11,355
1985	125,931	21,699	75,302	12,783
1986	131,403	24,292	76,993	13,644

Source: U.S. Patent Office

Table 10: Japanese Patents Applied For and Granted, FY 1978-FY 1985

(cases)

	Applications		Granted	
	Total	By the U.S.	Total	To the U.S.
FY 1978	166,100	10,300	45,500	4,000
FY 1979	174,600	9,900	44,100	4,600
FY 1980	191,000	10,400	46,100	4,000
FY 1981	218,300	12,000	50,900	4,500
FY 1982	237,500	14,200	50,600	4,100
FY 1983	255,000	16,000	54,700	4,200
FY 1984	284,767	18,030	61,800	4,100
FY 1985	302,995	22,633	50,100	3,100

Source: Japanese Patent Agency

Table 11: Japan's Corporate Technology Trade by Industry, FY 1984-FY 1985

(number of cases and value in billions of yen)

	FY 1984				FY 1985			
	Exports		Imports		Exports		Imports	
	Cases	Value	Cases	Value	Cases	Value	Cases	Value
Total	5,426	Y277.5	7,316	Y281.4	5,885	Y234.2	7,679	Y293.2
Agriculture	18	0.2	0	0.0	8	0.2	0	0.0
Mining	15	0.4	14	0.2	17	0.4	22	0.2
Construction	712	44.6	307	2.3	384	26.5	380	3.5
Manufacturing	4,660	231.9	6,979	276.9	5,449	205.6	7,265	288.6
Food Products	175	6.8	178	9.5	113	6.1	81	10.4
Textiles	106	3.9	215	9.4	152	4.0	233	3.3
Pulp and Paper	47	1.4	36	1.4	43	1.1	38	1.6
Publishing	12	0.1	33	0.5	17	0.1	49	0.6
Chemicals	888	37.5	784	40.8	972	38.2	810	37.4
Synthetic Fibers	421	19.1	429	15.3	452	19.8	427	13.6
Fertilizers	169	2.6	153	3.7	180	2.3	133	3.7
Pharmaceuticals	204	13.7	123	13.8	239	13.1	166	13.1
Other	94	2.1	79	7.9	101	3.1	84	7.1
Petroleum and Coal Products	31	0.6	97	3.0	9	0.6	99	5.2
Plastic Products	57	0.5	92	1.6	66	1.2	118	3.1
Rubber Products	53	2.3	118	3.3	61	2.7	112	3.2
Nonmetallic Mineral Products	196	11.2	186	8.4	344	9.5	287	32.4
Steel	411	32.4	316	5.6	393	26.2	274	4.7
Nonferrous Metals	133	1.9	170	5.1	162	1.9	200	5.1
Fabricated Metal Products	133	1.3	199	3.6	152	2.4	209	3.9
Nonelectric Machinery	543	11.4	1,109	23.9	588	11.7	979	24.5
Electric Machinery	1,095	47.2	2,190	94.9	1,439	59.5	2,481	84.2
Machine Tools	434	14.2	437	33.7	517	17.7	425	24.1
Electronics	661	33.0	1,753	61.2	922	41.7	2,056	60.1
Transportation Equipment	526	39.8	883	55.2	777	32.4	873	59.7
Motor Vehicles	304	27.2	271	10.3	558	26.0	284	11.4
Other	222	12.6	612	45.0	219	6.4	589	48.3
Precision Machinery	71	1.8	191	4.4	57	1.7	266	5.1
Other	183	31.7	182	6.3	104	6.3	156	4.3
Transportation, Communications, and Utilities	21	0.4	16	2.1	27	1.6	12	0.9

Source: Management and Coordination Agency, Report on the Survey of Research and Development.

Table 12: Japan's Corporate Technology Trade by Country, FY 1982-FY 1985

(number of cases and value in billions of yen)

a. Exports

	FY 1982		FY 1983		FY 1984		FY 1985	
	Cases	Value	Cases	Value	Cases	Value	Cases	Value
Asia	2,470	Y111.6	3,084	Y119.2	2,549	Y112.5	3,047	Y87.5
China	101	4.5	236	18.4	918	53.1	976	34.3
Taiwan	447	9.7	655	10.8	512	10.0	559	7.9
Korea	485	7.5	903	17.0	598	14.9	798	18.2
Thailand	229	5.6	287	6.1	218	8.3	214	6.2
Philippines	127	2.3	131	13.5	111	0.6	320	4.4
Indonesia	227	14.8	273	15.8	228	13.6	174	5.2
North America	784	40.8	1,226	60.0	944	71.9	1,058	58.7
United States	654	35.6	1,069	53.6	751	65.9	896	51.8
South America	220	10.8	238	10.1	199	3.7	243	8.7
Brazil	110	7.3	133	7.9	107	1.9	133	3.3
Europe	835	39.0	1,597	37.1	993	40.7	1,072	45.5
Great Britain	118	8.4	469	5.3	168	6.8	183	5.3
West Germany	152	4.7	431	5.1	217	4.7	253	11.3
France	121	3.9	144	4.5	141	4.6	129	4.8
Netherlands	31	1.0	46	2.4	38	2.1	41	4.8
Switzerland	58	2.1	52	2.1	42	4.9	44	3.3
Africa	314	12.4	137	9.2	222	12.8	135	6.6
Oceania	115	5.5	121	5.3	133	5.1	163	13.0

b. Imports

	FY 1982		FY 1983		FY 1984		FY 1985	
	Cases	Value	Cases	Value	Cases	Value	Cases	Value
Asia	111	Y0.7	10	Y0.2	63	Y0.3	169	Y0.9
China	1	*	3	*	53	0.2	115	0.8
Taiwan	1	*	2	*	51	0.1	1	*
Korea	41	0.5	1	*	8	0.1	52	0.0
North America	4,158	188.6	4,757	194.0	4,437	194.0	4,814	210.3
United States	4,062	187.0	4,698	191.1	4,335	193.0	4,772	208.6
South America	1	*	3	*	26	0.0	1	*
Europe	2,618	92.7	3,025	84.5	2,750	86.7	2,664	81.6
West Germany	803	17.8	832	19.6	975	17.8	859	17.6
Great Britain	462	25.0	480	147	429	13.2	566	14.6
France	333	10.9	401	11.4	374	10.4	285	6.8
Switzerland	326	15.7	335	15.9	269	16.0	319	16.3
Netherlands	150	12.7	151	11.3	156	14.1	156	15.5
Africa	5	0.3	4	*	5	0.0	1	*
Oceania	43	0.4	40	0.4	33	0.3	28	0.3

*Less than Y50 million.

Source: Management and Coordination Agency, Report on the Survey of Research and Development.

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